TOP QUARK PRODUCTION CROSS SECTION AT THE TEVATRON

E. SHABALINA
for the CDF and DØ collaborations
University of Illinois at Chicago, Chicago IL, USA 60612

An overview of the preliminary results of the top quark pair production cross section measurements at a center-of-mass energy of 1.96 TeV carried out by the CDF and DØ collaborations is presented. The data samples used for the analyses are collected in the current Tevatron run and correspond to an integrated luminosity from 360 pb^{-1} up to 760 pb^{-1}.

1 Introduction

The top quark was discovered [1] in 1995 at the Fermilab Tevatron $p\bar{p}$ Collider at $\sqrt{s} = 1.8$ TeV based on about 50 pb^{-1} of data per experiment. The increased luminosity and higher collision energy of $\sqrt{s} = 1.96$ TeV of the current Tevatron run allow precise measurements of the top quark production and decay properties. The latest theoretical calculations [2] for the $t\bar{t}$ production cross section ($\sigma_{t\bar{t}}$) at NLO have an uncertainty ranging from 9% to 12%. The precise measurement of $\sigma_{t\bar{t}}$ is not only of interest as a test of perturbative QCD, but it also permits to probe the effects of new physics. Such effects could lead to the $t\bar{t}$ cross section dependent on the final state of the top quark pair. It is therefore necessary to measure $\sigma_{t\bar{t}}$ in all decay channels.

In the Standard Model (SM), the top quark decays almost 100% of the time to a W boson and b-quark. Therefore, in $t\bar{t}$ events the final state is completely determined by the W boson decay modes. This paper covers the recent top quark pair cross section measurements performed by CDF and DØ in the dilepton channels, where both W bosons decay leptonically into an electron or a muon (ee, $e\mu$, $\mu\mu$), in the lepton + jets channels, where one of the W bosons decays leptonically and the other one hadronically (e+jets, μ+jets), and in the all hadronic channel, where both W bosons decay hadronically.

Table 1: Summary result in the dilepton channels obtained by CDF (in number of events).

Source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
Total background	6.10±1.87	7.52±2.12	5.72±1.38	19.34±4.26
$t\bar{t}$ ($\sigma_{t\bar{t}} = 6.7$ pb)	8.25±0.38	8.57±0.39	19.27±0.88	36.09±1.24
Total SM expectation	14.35±2.08	16.09±2.30	24.99±1.75	55.43±5.11
Candidates in 750 pb^{-1}	12	24	28	64

2 Dilepton channel

In the detector a dileptonic final state is characterized by the presence of two isolated high p_T leptons, two high p_T b-jets and a large missing transverse energy ($\not{E}_T$) from the two neutrinos. The background contributions are pure instrumental effects, entirely estimated from data, and irreducible physics backgrounds, derived from Monte Carlo simulations. Sources of the former are multijet, W+jets and $Z \to \ell\ell$ events with mismeasured $\not{E}_T$, misidentified jets or misidentified isolated electrons or muons, whereas the latter mainly include $Z \to \tau\tau$ where the τ leptons decay leptonically, and WW/WZ (diboson) processes.

A summary of the expected $t\bar{t}$ signals, backgrounds and observed number of candidate events in a dataset corresponding to the integrated luminosity of 750 pb^{-1} in the dilepton channels obtained by CDF is presented in Table 1. The preliminary quoted $t\bar{t}$ cross section for $m_{top} =$ 175 GeV yields $\sigma_{t\bar{t}} = 8.3 \pm 1.5(\text{stat}) \pm 1.0(\text{syst}) \pm 0.5(\text{lumi})$ pb.

The inclusive analysis performed by CDF makes an attempt to fit several SM processes that constitute the dilepton sample taking advantage of their separation in the $\not{E}_T$-N_{jet} phase space. $t\bar{t}$ and WW events typically have large $\not{E}_T$ from the final state neutrinos, but $t\bar{t}$ events have more jet activity. Conversely, $Z \to \tau\tau$ events have small $\not{E}_T$ originating from leptonic decays of τ's, and low jet activity. Cross sections extracted from fitting of the two dimensional $\not{E}_T$-N_{jet} distribution from the data to those from the expected SM contributions are summarized in Table 2. In the case of the ee and $\mu\mu$ channels only $t\bar{t}$ and WW cross sections are fitted since the additional cut on the $\not{E}_T$ significance applied in these channels to reduce large $Z \to ee(\mu\mu)$ backgrounds makes it hard to extract the $Z \to \tau\tau$ cross section. The measured cross sections are in good agreement with the SM predictions [a].

Table 2: Summary of the cross sections from the inclusive dilepton analysis for 360 pb^{-1} by CDF.

Cross section	$e\mu$	$\ell\ell$
$t\bar{t}$	$9.3^{+3.1}_{-2.6}$(fit)$^{+0.7}_{-0.2}$(shape) pb	$8.4^{+2.5}_{-2.1}$(fit)$^{+0.7}_{-0.3}$(shape) pb
WW	$12.3^{+5.3}_{-4.4}$(fit)$^{+0.5}_{-0.1}$(shape) pb	$16.1^{+5.0}_{-4.3}$(fit)$^{+0.8}_{-0.2}$(shape) pb
Z/DY $\to \tau\tau$	$292.7^{+48.9}_{-45.1}$(fit)$^{+5.9}_{-2.9}$(shape) pb	

The statistical sensitivity of the dilepton channel can be improved by loosening the lepton identification criteria and selecting events with one well identified high p_T lepton and one high p_T isolated track and considering events with at least one jet. Additional discrimination of the $t\bar{t}$ signal from the backgrounds is achieved by using b-jet identification (b-tagging). To distinguish a heavy-flavor jet (arising from a b- or c-quark) from a light-flavor jet (u-, d-, s-quark or gluon) one can make use of the presence of charged tracks significantly displaced from the primary vertex due to the finite lifetime of the B- or D-meson (lifetime tagging). DØ measured $\sigma_{t\bar{t}}$ using lepton plus track events with one or more jets tagged by a lifetime b-tagging algorithm

[a] $\sigma_{t\bar{t}}$ is given for $m_{top} = 178$ GeV.

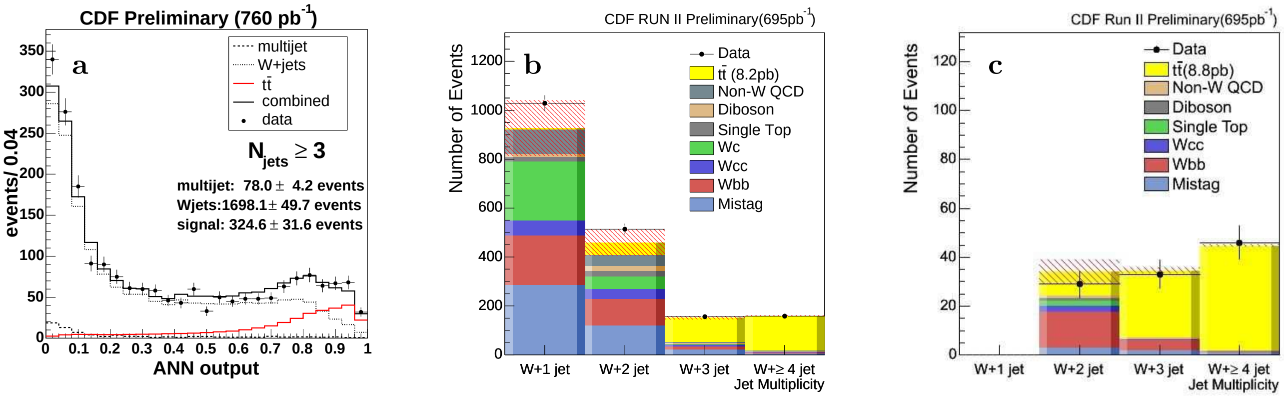

Figure 1: (a) Observed ANN output distribution versus fit result for $W+\geq3$ jet events; summary of backgrounds and measured $t\bar{t}$ signal with at least one tag (b) and $\geq$ 2 tags (c) compared to the observed number of tagged events in data as a function of jet multiplicity. The band in (b) and (c) shows $\pm1\sigma$ variation of the background.

and combined it with the cross section extracted from $e\mu$ events [b]. The combined cross section based on a 370 pb^{-1} dataset yields $\sigma_{t\bar{t}} = 8.6^{+1.9}_{-1.7}(\text{stat}) \pm 1.1(\text{syst}) \pm 0.6(\text{lumi})$ pb.

3 Lepton + jets channel

The signature of the ℓ+jets channel consists of one isolated high p_T lepton, $\not\!\!E_T$ due to the neutrino and at least four jets. The dominant background processes are W+jets and multijet production. To discriminate signal from background, which is significantly higher in ℓ+jets channels compared to the dilepton ones two approaches are used. The first approach makes use of the distinct kinematic features of a $t\bar{t}$ event arising from its large mass. It combines kinematic event information into a discriminant or artificial neural network (ANN) and performs a fit to the data. The second approach requires that at least one of the jets per event is identified as a b-jet. In both approaches, at the first stage of the analysis a data sample enriched in W+jets and $t\bar{t}$ events is defined. The remaining QCD multijet background originates primarily from π^0's and γ's misidentified as jets (e+jets channel) or from heavy flavor decays (μ+jets channel), and is evaluated directly from data.

CDF uses the ANN technique employing information from seven input variables providing good discrimination between $t\bar{t}$ signal and W+jets background. The results of the fit are shown in Fig.1(a) for the events with 3 or more jets. The corresponding $t\bar{t}$ cross section for a luminosity of 760 pb^{-1} is $\sigma_{t\bar{t}} = 6.0 \pm 0.6(\text{stat}) \pm 0.9(\text{syst})$ pb.

Both CDF and DØ have measured $\sigma_{t\bar{t}}$ using lifetime tagging algorithms performing explicit reconstruction of secondary verteces with a large decay length significance with respect to the primary vertex. DØ extracts the $t\bar{t}$ production cross section from the excess observed in the actual number of tagged events in e+jets and μ+jets data with 3 and $\geq$ 4 jets and with exactly one and two or more tags with respect to the background expectation. Each source of systematic uncertainty included through a Gaussian term into the likelihood function used for the $\sigma_{t\bar{t}}$ calculation is allowed to affect the central value of the cross section, thus yielding a combined statistical and systematic uncertainty on $\sigma_{t\bar{t}}$. Assuming a top quark mass of 175 GeV DØ measures $\sigma_{t\bar{t}} = 8.1^{+1.3}_{-1.2}(\text{stat} + \text{syst}) \pm 0.5(\text{lumi})$ pb using a dataset of 360 pb^{-1}.

In order to further reduce dominant backgrounds in the inclusive three jet sample with at least one b-tag, CDF requires that the scalar sum of the lepton p_T, jet E_T, and missing E_T, H_T, is larger than 200 GeV. Cross section measurement using a dataset of 700 pb^{-1} yields $\sigma_{t\bar{t}} =$

[b] $e\mu$ events with well identified electron and muon were vetoed in the lepton plus track analysis.

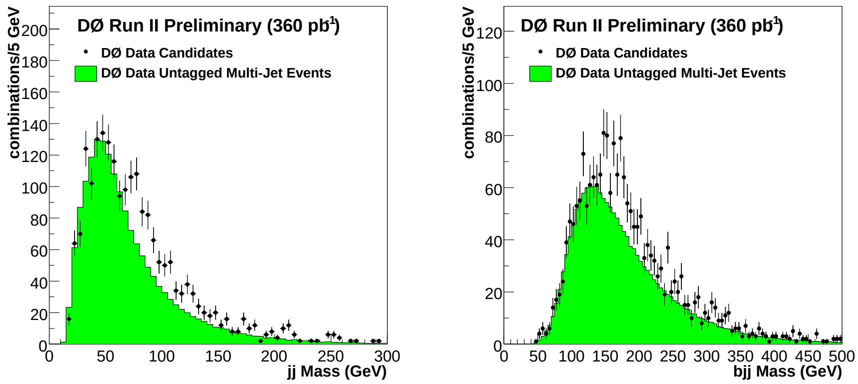

Figure 2: The dijet mass spectrum for all pairs of non b-tagged jets (left) and the three-jet mass spectrum for all combinations of one b-tagged jet and two non-b tagged jets (right) with background overlayed.

8.2 ± 0.6(stat) ± 1.0(syst) pb, the most precise single measurement of $\sigma_{t\bar{t}}$ so far. The cross section extracted from the sample with ≥ 3 jets and at least two tags is $\sigma_{t\bar{t}} = 8.8^{+1.2}_{-1.1}(\text{stat})^{+2.0}_{-1.3}(\text{syst})$ pb. Contributions of various backgrounds and measured $t\bar{t}$ signal compared to the observed number of tagged events for different jet multiplicity bins are summarized in Figures 1(b,c).

4 All hadronic channel

The all hadronic final state is characterized by six high p_T jets two of which are b-jets. The dominant background in this channel, multijet production, is orders of magnitude larger than the $t\bar{t}$ signal making the latter hard to identify. On the other hand, the absence of the neutrinos in the final state allows to fully reconstruct the $t\bar{t}$ signal and thus discriminate it from the background. DØ performs a $\sigma_{t\bar{t}}$ measurement by utilizing the three jet invariant mass distribution where one of the jets is identified as a b-jet and the other two are light jets for background normalization. Fig. 2 shows the dijet mass spectrum for all pairs of light jets revealing a W boson peak (left) and the three jet mass spectrum (right). The shape of the overlaid background is determined from data by assigning b-flavor to a random jet. The excess of events over the background is attributed to the top quark production. The cross section measured using a 360 pb^{-1} dataset yields $\sigma_{t\bar{t}} = 12.1 \pm 4.9(\text{stat}) \pm 4.6(\text{syst})$ in agreement with SM.

5 Conclusion

Both CDF and DØhave significantly improved the accuracy of the $t\bar{t}$ cross section measurements in all decay channels using data collected in the current Tevatron run. CDF has combined six measurements of $\sigma_{t\bar{t}}$ achieving a 15% improvement in the absolute uncertainty with respect to the best single measurement. The combined result for m_{top}=175 GeV, $\sigma_{t\bar{t}} = 7.3 \pm 0.5(\text{stat}) \pm 0.6(\text{syst}) \pm 0.4(\text{lumi})$, is in good agreement with the theoretical prediction. Measurements in all decay channels are consistent with each other and with the combined result.

References

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2. M. Cacciari, S. Frixione, G. Ridolfi, M. Mangano and P. Nason, JHEP **404**, 68 (2004); N. Kidonakis and R. Vogt, *Phys. Rev.* D **68**, 114014 (2003).